Pelagic *Sargassum* in the North Tropical Atlantic: Mortality, Growth, and Seasonal Prediction

Sargassum Pelágico en el Atlántico Tropical Norte: Mortalidad, Ccrecimiento y Predicción Estacional

Pelagic Sargassum dans L'Atlantique Nord-Tropical: Mortalité, Croissance et Prévision Saisonnière

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ABSTRACT

In this study, we discuss results from a Russian sea floor survey over the Mid-Atlantic Ridge north of the North Equatorial Recirculation Region where large quantities of pelagic *Sargassum* were found both at the surface, and along the bottom in different stages of decomposition. Model backtracks from the survey location trace this *Sargassum* to the Gulf of Guinea along an extensive, indirect path where significant growth and mortality must have occurred. Growth and mortality of pelagic *Sargassum* are key parameters necessary for quantifying model based forecasts of *Sargassum* events when long transport times and distances are involved. It is also necessary for understanding important issues such as global carbon sequestration and potential increases in fishery biomasses. But it is poorly known. Previous work on mortality has focused on (1) beaching and (2) sinking to bladder failure depths in Langmuir cells. Predation is not considered a major mortality factor. Beaching, although impressive locally, in the long term can only account for a small percentage of mortality needed to balance the growth rate. We discuss breaking of *Sargassum* plants by wave action, Langmuir Cells, Langmuir Mixing and the need for relatively simple but standardized measurements of mortality by sinking.

KEYWORDS: *Sargassum*, mortality, langmuir, carbon sequestration, fishery, biomass

INTRODUCTION

In 2014, the western region of the North Equatorial Recirculation Region (NERR; Johnson et al. 2012, Figure 1A) experienced an exceptionally high *Sargassum* presence (Wang and Hu 2016) with significant transport into the Caribbean as well as reflection back toward the eastern NERR through the North Brazil Current Retroflection (NBCR). In boreal winter the North Equatorial Counter Current (NECC), which transports the reflected Sargassum eastward (e.g., Gower et. al. 2013), breaks down and flow reverses toward the west and northwest. During winter reversal the eastern consolidation region expands westward (Figure 1B) and a portion of the *Sargassum* that has bloomed and recirculated along the northern limb of the NERR is in position for entrainment into the North Equatorial Current (NEC) where direct return to the NERR is unlikely. In addition, the long transport time-scales involved (seasonal and yearly) make it clear that growth and mortality rates will become critical factors for estimating mass abundance in prediction modeling. Growth and mortality rates are also of major importance for issues such as carbon sequestration (Milledge and Harvey 2016) and changes in *Sargassum* dependent fishery biomass (Casazza and Ross 2008).

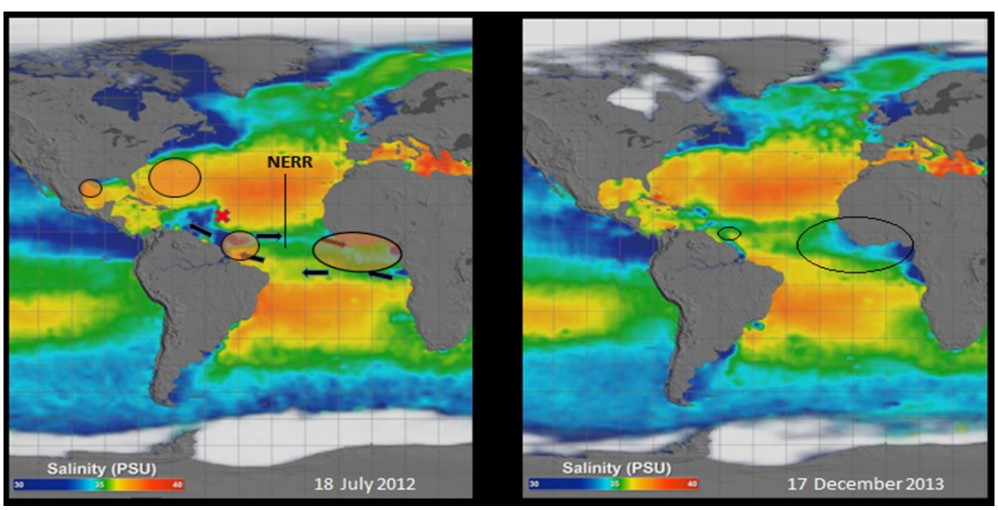

Figure1. Sea surface salinity from NASA Aquarius satellite.
A — summer. B — winter. Ellipses show pelagic *Sargassum* consolidation areas.
Black arrows are schematic surface currents. Red cross – Russian survey area.

During winter following the strong 2014 event season in the western Tropical Atlantic region, *Sargassum* was encountered (Molodtsova et al. 2016) in Russian ecological surveys conducted north of the NERR ($\sim 5^{o}$ S to 10^{o} N) on the Mid-Atlantic Ridge at $\sim 17^{o}$ N (Figure 1A). Massive amounts of pelagic *Sargassum* were found at the surface from December 2014 through April 2015. More importantly, it was seen in 'different states of degradation' on the bottom by TV monitoring. It was identified as *S. fluitans*, one of two common species in the Sargasso Sea. Furthermore, beginning in November of 2014, Schell et al. (2015) collected *Sargassum* at the surface in an east-west transect of the general Russian survey area and related the majority species and form (*S. natans* VIII) to the Tropical North Atlantic rather than the Sargasso Sea.

In this study, we use archived surface currents from the Hybrid Coordinate Ocean Model (Hycom; Bleck 2002) to back track *Sargassum* (water parcels) from the Russian survey area and sampling date (February - March 2015) to the beginning of 2014 (13 - 14 months back in time). Using the same starting locations and times, *Sargassum* is forward traced until the end of 2015 (9 - 10 months). Since one of the most surprising results of the survey was the amount of reported *Sargassum* in decay along the bottom, it is worth putting into the discussion some ideas of mortality by sinking.

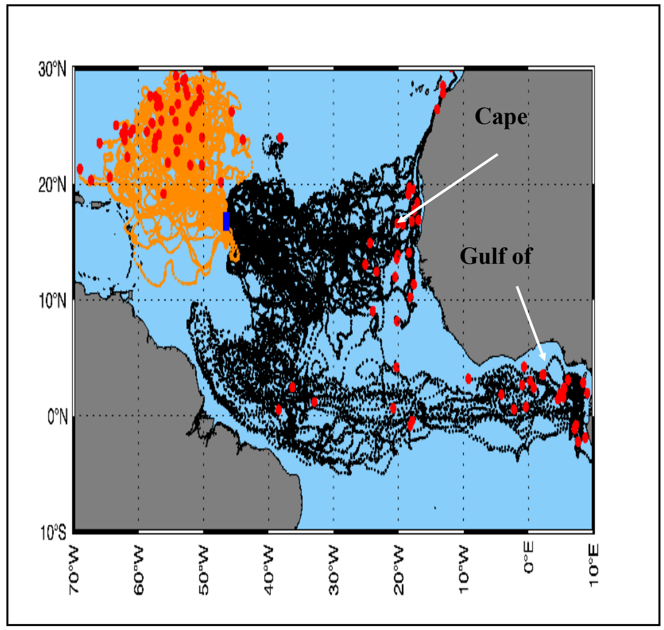

Figure 2. Back tracks (black) and forward tracks (orange) from Russian survey site (Blue). Red dots show origin (back tracks) or ending positions (forward tracks).

TRACKING PELAGIC *SARGASSUM* OUTSIDE THE NERR

It should be noted that algorithms which use numerical modeled ocean currents for tracking from a starting location and date are tracing the path of a parcel of water which may contain *Sargassum*. Our study uses a general area and a general span of time rather than isolated events so some parcels may contain *Sargassum* and some may not. Results of both backward and forward tracks from the Russian survey dates and locations show patterns which were expected, but still surprising (Figure 2).

Clearly there are two distinctive potential sources (from backtracks), one is in the Cape Verde Island area which is under influence of the Canary Current, an eastern limb of the North Atlantic gyre feeding into the North Equatorial Current (NEC), and one is in the Gulf of Guinea off West Africa. Since massive *Sargassum* events have not been reported in the Cape Verde Island area, it is likely that the *Sargassum* reported over the Mid-Atlantic Ridge location had an origin in the Gulf of Guinea where it has been reported (Solarin et al. 2014). Beginning in boreal winter 2013/2014, according to the model track, it would have been transported along an equatorial path to the NE coast of Brazil where it was reflected eastward in the NBCR. It is suggested that during the subsequent boreal winter of 2014/2015, some of this water was carried northwestward and entrained in the NEC. This supports Franks et al. 2016 where model backtracking and satellite tracked drifters pointed to the Gulf of Guinea as an important location for consolidation and bloom in the eastern North Tropical Atlantic with winter entrainment of *Sargassum* into the westward flowing South Equatorial Current (SEC). Forward tracking from the Russian survey region, indicates that this water is transported westward where it appears to spread across a broad area with potential impact on the northern Caribbean and the Sargasso Sea.

This study agrees with the basic consolidation/ transport patterns in the NERR as put forward by Franks et al. (2016) and further suggests that bloom in the NERR may support the Sargasso Sea rather than the reverse.

GROWTH AND MORTALITY

Prediction of pelagic *Sargassum* beaching events in the NERR involves satellite recognition (Gower and King 2006, Hu 2009) to identify consolidated masses, as well as ocean model forecasts to estimate arrival times (e.g., Johnson et al. 2016). But the models presently lack information on both growth and mortality, which are necessary for quantifying *Sargassum* events. There have been previous studies (Hanisak and Samuel 1987, Lapointe et al. 2014) on growth rates showing wide variations with high dependency on nutrient availability and, hence, location. The NERR has a variety of nutrient sources, including the Amazon and Congo River outflows, multiple river outflows into the Gulf of Guinea, equatorial upwelling, upwelling along the coast of West Africa and dust from the Bodélé depression in Chad (Bristow et al. 2010). This broad source distribution must create substantial growth rate location dependencies. The difficulty in applying a single growth rate to modeled transport in the NERR can be readily seen by applying previously determined (LaPointe 1995) neritic (high nutrient, ~0.09 doublings/day) and oceanic (low nutrient, ~0.02 doublings/ day) rates. Assuming the maximum mass of *Sargassum* in the Sargasso Sea is around 11 million tonnes (Parr 1939, Gower and King 2011) then, without mortality, it would take from 1 month to 6 months for 1 million tonnes to grow to this maximum, depending on which growth rate is used. Since beaching events are not likely to match this level of growth, it seems clear that at-sea mortality must be on the scale of this high growth rate if yearly mean abundance is steady.

Efforts to quantify at-sea mortality have generally focused on sinking to bladder failure depths in fronts and Langmuir cells (Johnson and Richardson 1977). Using acoustic scattering surveys and nets, *Sargassum* thalli at depth have indeed been strongly linked to convergence lines. However, it is not clear that bladder failure is the main issue, nor that Langmuir cells in steady state (Figure 3) are sufficiently prevalent to account for the principal mortality by bladder failure. Thalli breakage due to turbulence in strong wave action together with weakness in parts due to epiphyte growth may contribute to pieces of *Sargassum* being detached with insufficient floatation. Langmuir cells and convergence at fronts can certainly accumulate these pieces. However, divers have described what seems like a 'rain' of *Sargassum* particles under mats where convergent currents are not obvious (H. Oxenford, *Personal communication*). This suggests that sinking may be more broadly dispersed than previously suspected.

Langmuir mixing (LM; McWilliams et al. 1997), a variant of Langmuir cell dynamics, has become an important part of understanding mixed-layer dynamics/air-sea interactions and may be important to at-sea mortality of *Sargassum* through dispersed distribution of sinking. Langmuir cells arise from instabilities, with relatively rapid inception and demise. LM comes from a jumble of Langmuir cell formation, decay and reformation with shifting locations. This process creates deep turbulent convection in the mixed-layer, much greater than the commonly understood frictionally induced turbulent eddies, and is spread over a broad area rather than being confined to temporal windrows. Thalli pieces, then, can be spread throughout the mixed layer over a large area. Important parameters for forcing mortality are winds and depth of the thermocline. A shallow thermocline inhibits full development of Langmuir cells. It is important to note that depth of the thermocline (Fig. 4A, from Montégut et al. 2004) and wind power (Fig. 4B, from Renewable Energy Science and Technology) and are both reduced off West Africa in comparison to the western Tropical Atlantic. This would suggest that at-sea mortality is likely as regional as nutrient formed growth rates. It also addresses the question of regional bloom. Could the original bloom of *Sargassum* in the north Tropical Atlantic in 2010/2011 be driven as much by reduced mortality in the eastern NERR as by enhanced nutrients?

Quantifying at-sea mortality may require a coordinated effort to measure thalli in the mixed layer (or below) in different locations and under varied environmental conditions. This may involve towing nets, or designing collection traps, optical imaging and sampling in coordination with satellite/aircraft surveys. The coordinated and standardized measurement of marine snow (Asper 1987) has many parallels to our present need to measure mortality of *Sargassum* by sinking. Its importance in predictive modeling, carbon sequestration and fishery biomass should make this effort a high priority.

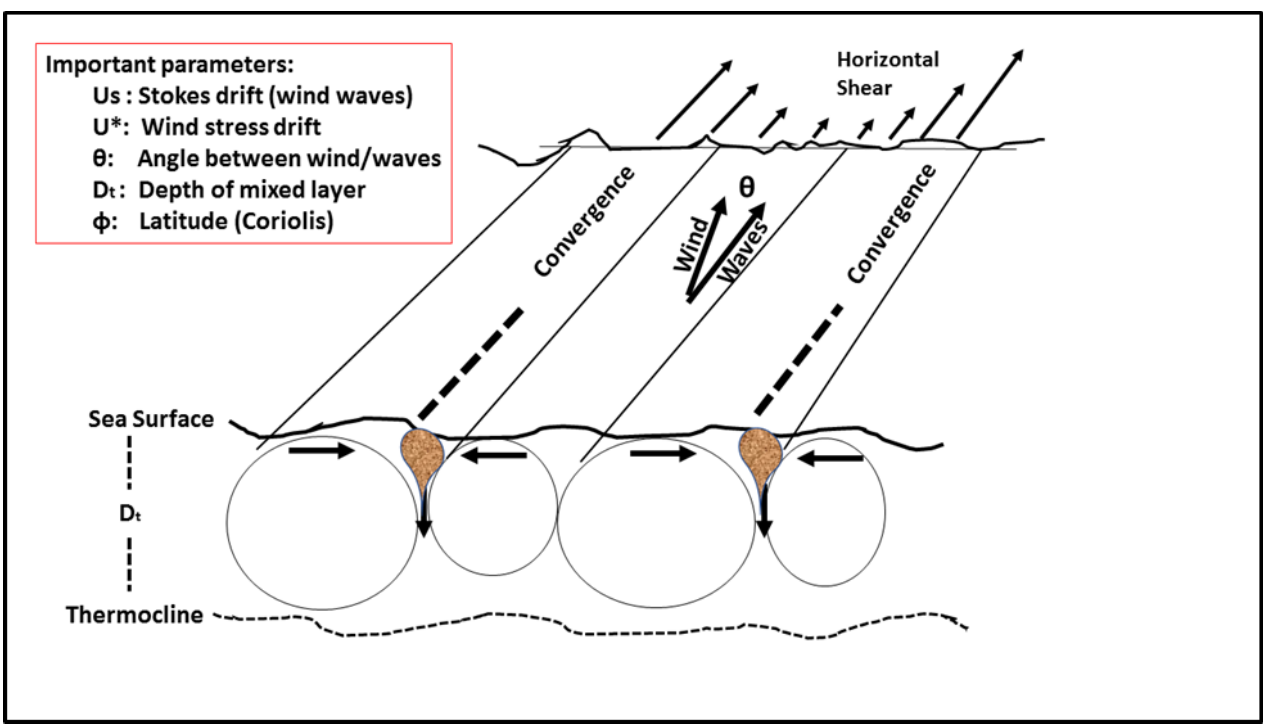

Figure 3. Schematic of Langmuir cell with important driving parameters.

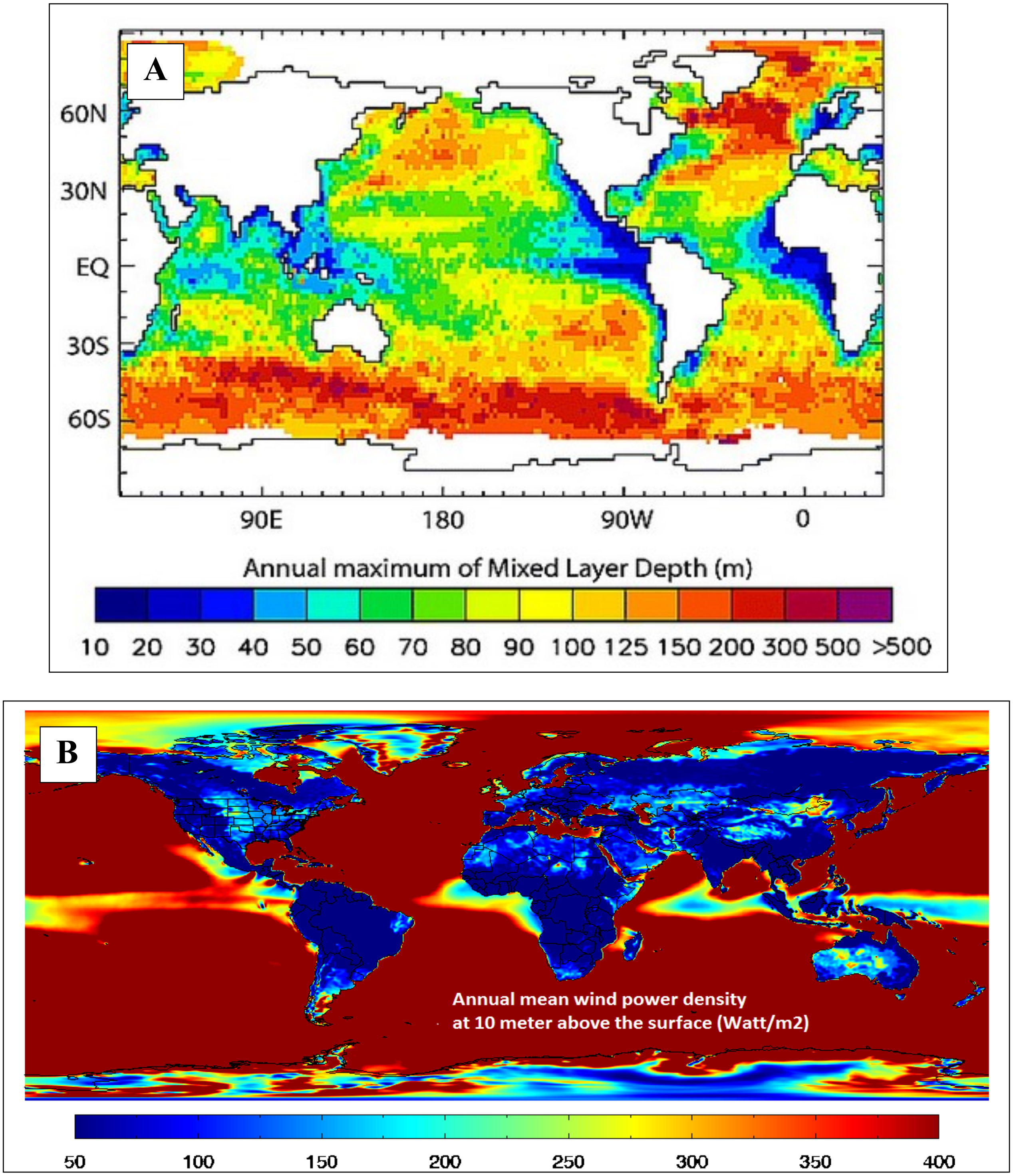

Figure 4. **(A)** Maximum mixed layer depth
(B) Maximum wind power

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